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Calc-alkaline lamprophyres from the Pilbara Block, Western Australia

Nicholas M S Rock & Mark E Barley

Department of Geology, University of Western Australia, Nedlands, WA 6009

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Abstract

A suite of calc-alkaline lamprophyre (dominantly spessartite) dykes and plugs forms a belt extending for some 250 km from Balfour Downs to north of Bamboo Creek in the eastern Pilbara. The lamprophyres show characteristic panidiomorphic texture and chemistry (eg. high F, Ba & K), and many are satellite to granitoid plutons. Available data suggest that these lamprophyres, many of which were formerly recorded as "hornblende porphyries", constitute basic members of a Proterozoic (c1700-1800 Ma) calc-alkaline, lamprophyre-porphyry-granitoid intrusive suite which mirrors younger suites worldwide. Lamprophyres are also known from the Shaw Batholith, in the eastern Pilbara, and from near Roebourne in the western Pilbara. Many other minor intrusions recorded as "hornblende porphyries", "trachyandesites", "diorites", "mafic porphyries" and "diabases" may also be lamprophyres. Lamprophyres form a significant phase of Pilbara magmatism, and thus are important to syntheses of tectonism, magmatism and mineralization.

Introduction

Lamprophyres (notably the lamproite subgroup) are now known to host or be spatially associated with deposits of diamond (at Argyle, in the Kimberley Region of Western Australia: Jaques *et al* 1986) and of gold (at Wood's Point, Victoria: Hills 1952). They can also be associated with carbonatites, which host deposits of phosphate and rare metals (*eg.* the Bow Hill lamprophyres of the east Kimberleys are contemporaneous with the Cummins Range carbonatite: Jaques *et al* 1985). Active exploration for lamprophyres is consequently being undertaken in Western Australia, and their very widespread distribution in this state (both in time and space) is becoming established: dykes, plugs and diatremes (ranging from Archaean to Miocene in age) have already been discovered or documented in many areas (Jacques *et al* 1985; 1986; Rock *et al* 1987).

This paper aims to reappraise: (1) all previously reported occurrences of "lamprophyres" in the Pilbara Block and (2) a few rocks formerly described under other names, which we also believe to be lamprophyres. It complements an extensive study of lamprophyres in the Yilgarn Block (Rock *et al* 1988). Petrological nomenclature follows Streckeisen (1979) and Rock (1984, 1987, 1988) throughout.

As described in more detail by Rock *et al* (1987), the published literature, together with catalogues and computerized indexes to the rock collections of the Department of Geology of the University of Western Australia (UWA), the Geological Survey of Western Australia (GSWA), CSIRO Division of Minerals and Geochemistry (Floreat Park), and several mining companies, have been searched for specimens described either as "lamprophyres", or under names indicating possible lamprophyric affinities (eg. 'mafic porphyries' or 'hornblende porphyries'). These searches revealed only two previously recorded occurrences of "lamprophyres" from the Pilbara. Both of these were summarized by Miles (1945) in the first compilation of lamprophyres throughout Western Australia. Jaques *et al* (1985, 1986) added no information to Miles' account in their otherwise comprehensive reviews of Australian alkaline rocks.

Criteria for reappraising previously described rocks

Streckeisen's (1979) recommended list of lamprophyre field and petrographical characteristics can be expanded, into the following set of criteria, which also consider rock chemistry (Rock 1987). They are listed in approximately decreasing order of significance, although it is the *combination* of as many as possible of these features which is diagnostic of lamprophyres:

1) Very high whole-rock K, Ba, Sr, Rb, Th, light rare earth elements (REE), P, F, CO_2, S and SO_3 (1-3 orders of magnitude higher than in basaltic rocks), combined with moderate enrichments in Ti, Zr, Nb, basaltic levels of V, Cr, Co, and Ni, but near to below-basaltic levels of Y and heavy REE.

2) Abundance of primary biotite, amphibole, carbonates, zeolites, chlorite, epidote, fluorite, sulphates, etc;

3) Certain unusual chemical features of the constituent minerals, including exceptionally high Ti contents in biotite, amphibole and clinopyroxene, and exceptionally high Ba in biotite or K-feldspar;

4) Textural features, such as panidiomorphism, battlemented biotites, lack of felsic phenocrysts, or the presence of leucocratic globular structures (ocelli);

5) Occurrence as commonly xeonolithic minor intrusions (dykes, sills, pipes, diatremes) associated with breccias, tuffs, pyroclastics, etc.; complex to bizarre intrusive forms are common.

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The usefulness of characteristic (4) may be reduced in the Pilbara, because most Precambrian rocks have suffered low-grade metamorphism, which readily destroys textural characteristics and makes true meta-lamprophyres petrographically similar to metamorphosed intermediate and basic rocks. Relict lamprophyric textural idiosyncracies, such as "battlemented" biotites, consistently euhedral pseudormorphs after biotite, amphibole or pyroxene, and apatite phenocrysts, are nevertheless observable in the Pilbara rocks described as lamprophyres below.

In assessing whole-rock chemical data, we recognise that metasomatism (including K-metasomatism) is widespread in the Pilbara Block (eg. Barley 1984, *et al* 1984), and could have induced some of the lamprophyre characteristics in originally non-lamprophyric rocks, or destroyed the original character of true lamprophyres. We have therefore relied less on high K contents than the *combination* of high Ba, Rb, Sr, La and Ce, with high V, Cr, Co and Ni, while fully taking into account the petrography. Fortunately, sufficient data are also available for associated igneous rock-types (both Archaean and Proterozoic) to allow more objective, *comparative* assessments. The chemistry of the rocks here claimed as lamprophyres is so distinctly different from all these associated types that their identity is unquestionable. Figure 3 confirms the chemical similarity of the Pilbara lamprophyres to global averages.

A reappraisal of Pilbara lamprophyre occurrences

Old Fortune Copper Mine, Roebourne, Western Pilbara

Miles (1945: 4-5) recorded a "typical mica lamprophyre (kersantite)" with a "rude schistosity", occurring as a dyke in quartz-gabbro. The relevant GSWA sample (12579; section no. 95103) fully confirms Miles' identification, carrying chlorite pseudomorphs after abundant, 'battlemented' biotite phenocrysts highly characteristic of mica-lamprophyres (Rock 1984). Unfortunately, this particular rock is too chloritized, silicified and carbonated to be worth analyzing, and we know of no other available material from this locality to follow the identification further.

Shaw Batholith

A suite of ultramafic lamprophyre dykes was discovered during a Department of Geology (UWA) research program on this, one of the major Archaean granitoid batholiths of the Pilbara (Fig. 1; Bettenay *et al* 1981). These dykes, composed predominantly of sodic titanaugite and alkali to sodic-calcic amphiboles (arfvedsonite, kataphorite, etc.) are detailed in a companion paper (Bettenay *et al* 1988).

Eastern Pilbara

Miles' (1945) only other reported lamprophyre, from Bamboo Creek, is a rock with "scattered clear feldspar phenocrysts up to 2 mm diameter", which is "not typical of the family" but is "in all probability an altered form of original mica lamprophyre—near kersantite". Re-examination of the thin section (GSWA 12545/^{s}1868) indicates that this rock is a metamorphosed dolerite (epidiorite), and shows no lamprophyric characteristics.

However, some rocks occurring in the same general area, previously described as 'hornblende porphyrites' (Maitland 1905, Finnucane 1935, Noldardt & Wyatt 1962), and as 'hornblende porphyries' or 'trachyandesites' (Hickman 1978, Barley 1980, Lewis & Davy 1981, Hickman *et al* 1983), are undoubtedly lamprophyres. Indeed, lamprophyres have now been annotated as such on the Geological Survey of Western Australia's recently published *Balfour Downs* 1:250 000 sheet (Williams 1987). They form part of a suite of dykes and plugs, which extends for some 250 km from Balfour Downs to north of Bamboo Creek (Fig. 1). A suite of lamprophyres, intermediate porphyries and granitoids from near Bamboo Creek has now been dated at *c*1800 Ma by a Pb-Pb whole-rock isochron (Barley *et al* in prep.).

The most abundant lamprophyres, mapped as "hornblende porphyries" on the GSWA's earlier *Nullagine* and *Yarrie* 1:250 000 sheets (Hickman 1978, Hickman *et al* 1983) contain 15 to 30 per cent of panidiomorphic, dark green-brown hornblende and, more rarely, phlogopitic biotite phenocrysts, in a fine-grained, variably sericitized and carbonated, feldspathic groundmass carrying small apatite and magnetite euhedra. The hornblende may carry clinopyroxene cores, and is rhythmically zoned, chloritized or carbonated (Fig. 2). New data for three lamprophyre plugs—two satellite to the Bridget Adamellite (Hickman 1978), and one part of a composite spessartite-quartz monzonite plug near Bamboo Creek—are compared in Table 1 with analyses of the Bridget Adamellite (from Barley 1980). Other rocks in the eastern Pilbara that have broadly similar chemical composition are Archaean intermediate volcanics (Hickman 1983, Barley *et al* 1984). Although the SiO_2, MgO, Ni, and V contents of these rocks overlap those of the lamprophyres, the lamprophyres have consistently higher Ba (>800 ppm), Rb (>80ppm) and Sr (>650 ppm) than a suite of relatively unaltered Archaean intermediate volcanics (Barley 1980) with Ba <650 ppm, Rb <50 ppm and Sr <600 ppm.

Lewis and Davy (1981) employed the term 'trachyandesite' as a chemical description of hornblende-phyric dykes and plugs intruding the Mt Edgar Batholith, whilst noting that these rocks had higher K_2O than Le Maitre's (1976) average trachyandesite. The term is now inappropriate in terms of the revised IUGS chemical classification of igneous rocks (Le Bas *et al* 1986), as it implies alkaline affinities for calc-alkaline rocks, and does not recognize their textural, minor or trace element characteristics. The term 'porphyry' is equally inadequate. Instead, the exotic chemistry of these rocks (*eg.* reported Ba contents of 800-2000 ppm, and F contents of 800-1100 ppm, coupled with moderate Rb, Ce, etc.), their lack of feldspar phenocrysts, and their panidiomorphic mafic phenocrysts, indicate that they should be termed *spessartites* (calc-alkaline lamprophyres dominated by hornblende-plagioclase).

The spessartites commonly appear as plugs and dykes satellite to intermediate hornblende-plagioclase porphyries and hornblende-bearing monzonites to quartz monzonites, such as the Bridget Adamellite (Fig. 1, Hickman 1978, Barley 1980). Similar porphyry plugs and small granitoid intrusions are associated with lamprophyres in the Mt Edgar Batholith (Mt Edgar itself is a small, hornblende-plagioclase porphyry to quartz-monzonite plug) and near Bamboo Creek (Hickman 1978). Petrography and chemical analyses of the Bridget Adamellite (Table 1, Barley 1980) and hornblende-plagioclase porphyries from the Mt Edgar Batholith (Lewis & Davy 1981) indicate that although containing abundant modal quartz (up to 20 per cent by volume; visual estimate) most of these granitoids should be called monzonites or quartz monzonites rather than adamellites (using the terminology of Streckeisen 1976).

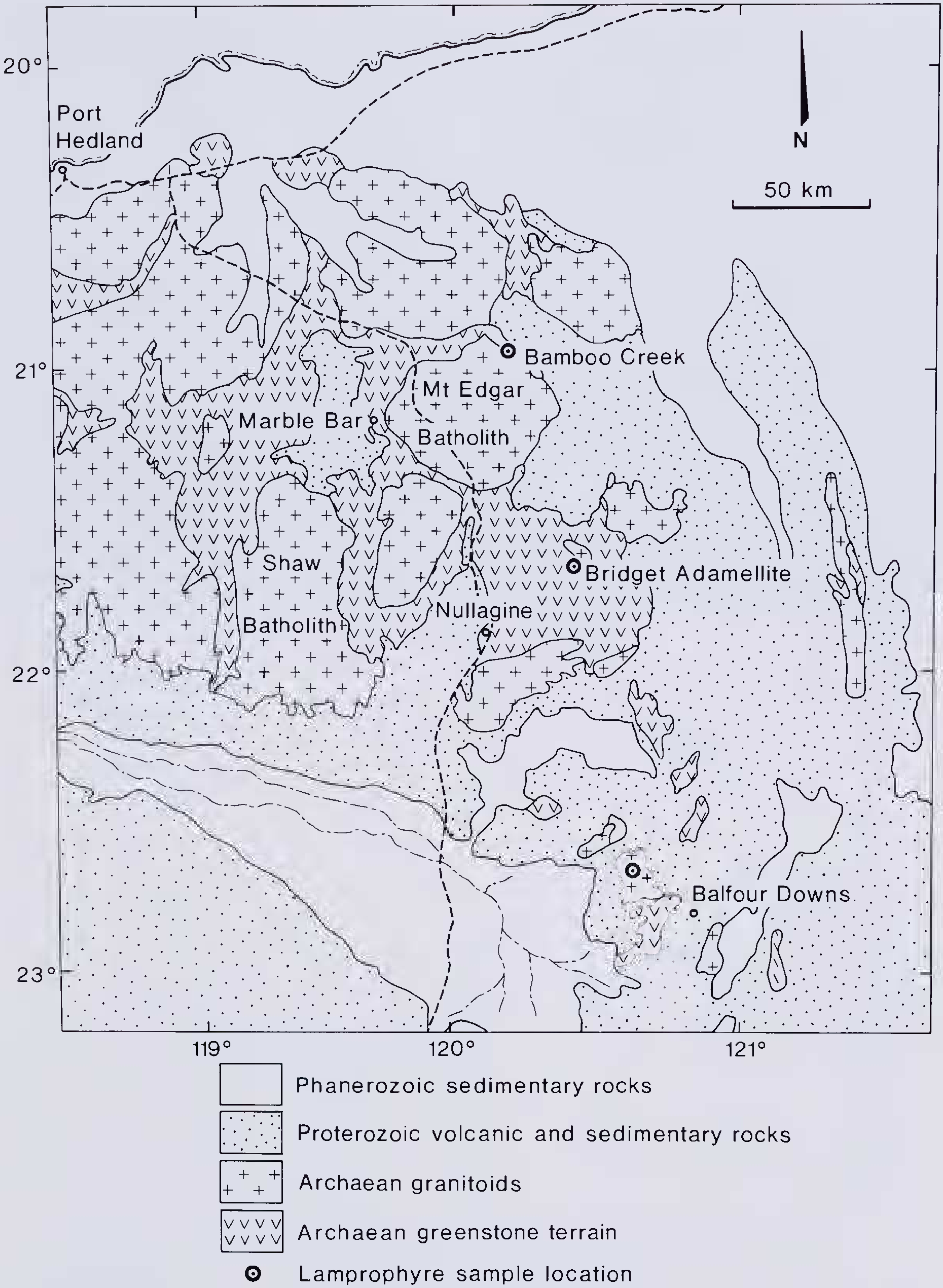

Figure 1 Locality sketch-map of the eastern Pilbara Block, showing general locations of known lamprophyres. Information largely taken from Geological Survey of WA 1:250 000 Series maps.

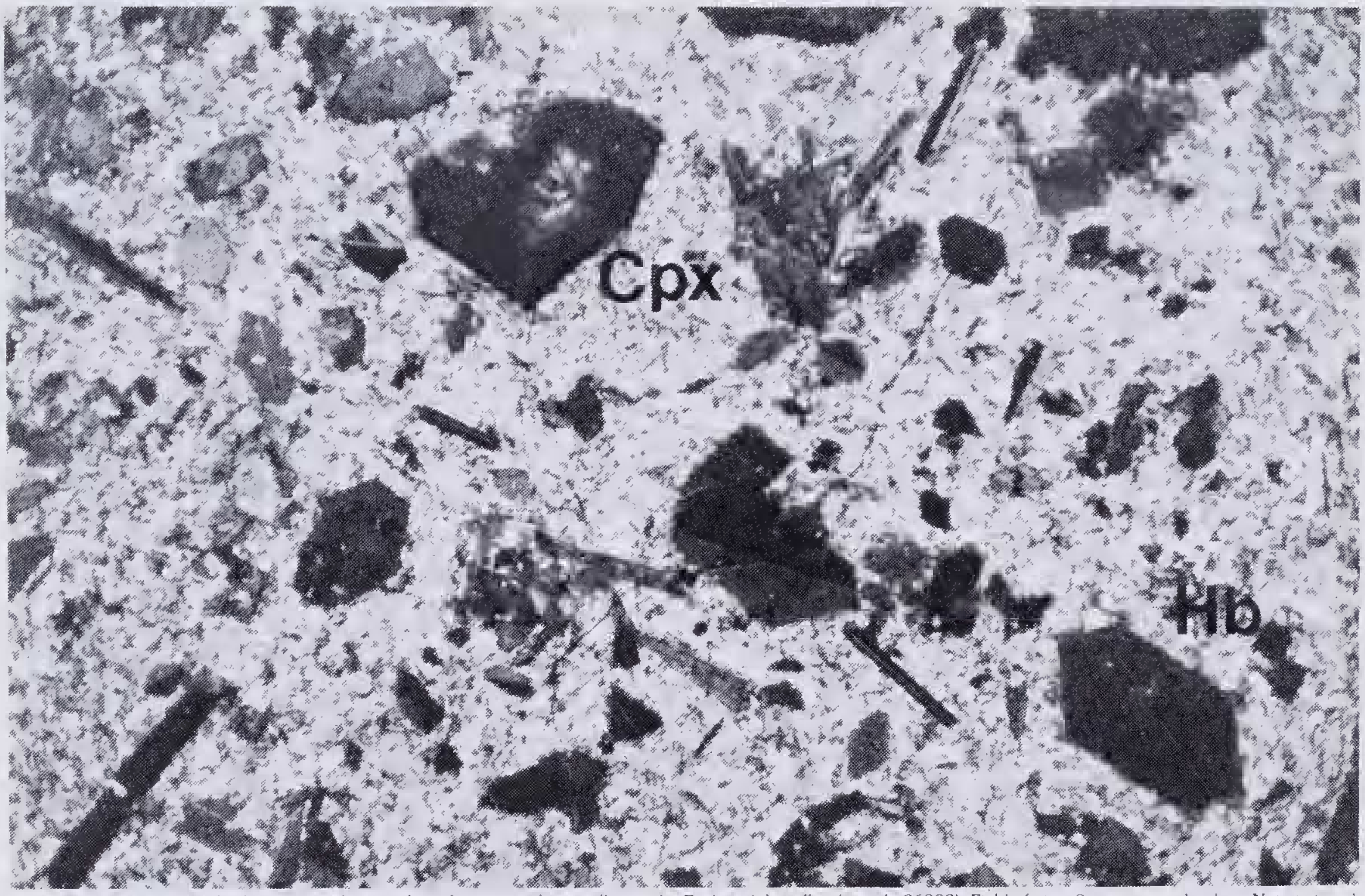

Figure 2 Photomicrograph of spessartite lamprophyre forming a plug satellite to the Bridget Adamellite (sample 86393). Field of view 8 mm; crossed polars. Note twinned, panidiomorphic hornblendes (**Hb**) one with a core of clinopyroxene (**Cpx**).

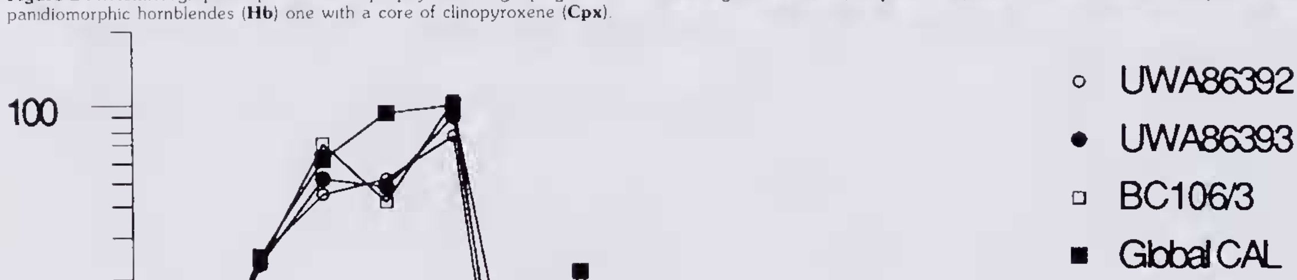

Figure 3 MORB-normalized multi-element plots ("spidergrams") of eastern Pilbara suite lamprophyres compared with average global calc-alkaline lamprophyres (pattern labelled "global CAL"). Data from Table 1 and Rock (1987). Elements are arranged such that their incompatibilities and immobilities increase towards the centre of the diagram (Pearce 1983).

Table 1

New analyses of confirmed lamprophyres and associated rocks from the Pilbara

	Lamprophyres			Bridget adamellite		
	Bamboo	Area of Bridget adamellite				
	BC106.3	UWA 86392	UWA 86393*	UWA 86389	UWA 86390	UWA 86391
SiO_2	58.79	58.89	58.44	63.54	63.82	64.76
Al_2O_3	15.24	14.02	14.08	14.67	14.53	14.84
Fe_2O_3	8.16	3.39	3.44	3.67	2.96	2.46
FeO	NA	4.96	4.72	2.54	3.08	2.78
MgO	3.36	4.11	4.41	2.35	2.38	2.33
CaO	5.66	5.97	6.11	4.19	4.22	4.31
Na_2O	3.42	3.91	3.02	3.51	3.49	3.51
K_2O	3.47	3.70	3.44	4.15	4.11	3.43
H_2O+	0.86	0.90	0.73	0.38	0.51	0.81
TiO_2	0.70	0.50	0.53	0.45	0.44	0.38
P_2O_5	0.29	0.30	0.36	0.23	0.24	0.24
MnO	0.15	0.19	0.12	0.13	0.11	0.08
CO_2	NA	0.05	0.33	0.19	0.30	0.23
Total	100.10	100.89	99.73	100.00	100.19	100.16
Trace elements (ppm), in order of atomic number						
V	152	197	169	NA	NA	NA
Ni	21	42	44	NA	NA	NA
Cu	8	37	100	26	45	28
Zn	68	84	97	74	74	58
Rb	140	90	104	132	129	123
Sr	675	715	690	670	670	623
Y	11	16	19	20	16	15
Zr	86	102	103	123	125	121
Nb	6	5	8	NA	NA	NA
Sn	2	NA	1	NA	NA	NA
Ba	840	1014	970	900	970	670
La	11	11	22	NA	NA	NA
Ce	76	86	92	NA	NA	NA
Pb	30	92	85	NA	NA	NA
Th	21	15	18	NA	NA	NA
CIPW weight % norms (analyses recalculated to 100% free of H_2O and CO_2						
qz	8.64	4.38	9.17	14.86	15.57	18.68
ab	29.33	33.11	25.83	29.87	29.66	29.92
or	20.78	21.88	20.55	24.66	24.39	20.42
an	16.20	9.78	14.86	12.08	11.89	14.71
di	8.49.	14.41	9.22	5.03	4.66	3.10
hy	10.94	10.81	13.92	8.83	8.96	8.92
mt	3.60	3.88	3.82	2.84	2.79	2.43
il	1.35	0.95	1.02	0.86	0.84	0.73
ap	0.68	0.70	0.84	0.54	0.56	0.56
cc	0.00	0.11	0.76	0.43	0.69	0.53
Total	100.00	100.01	100.00	100.00	100.00	100.00
DI†	58.75	59.37	55.56	69.39	69.62	69.02

†Thornton-Tuttle differentiation index NA=not analysed *see photomicrograph in Fig. 2.
Data from Barley (1980), supplemented with new trace element determinations using conventional XRF techniques (courtesy of Dr R Chang, UWA).

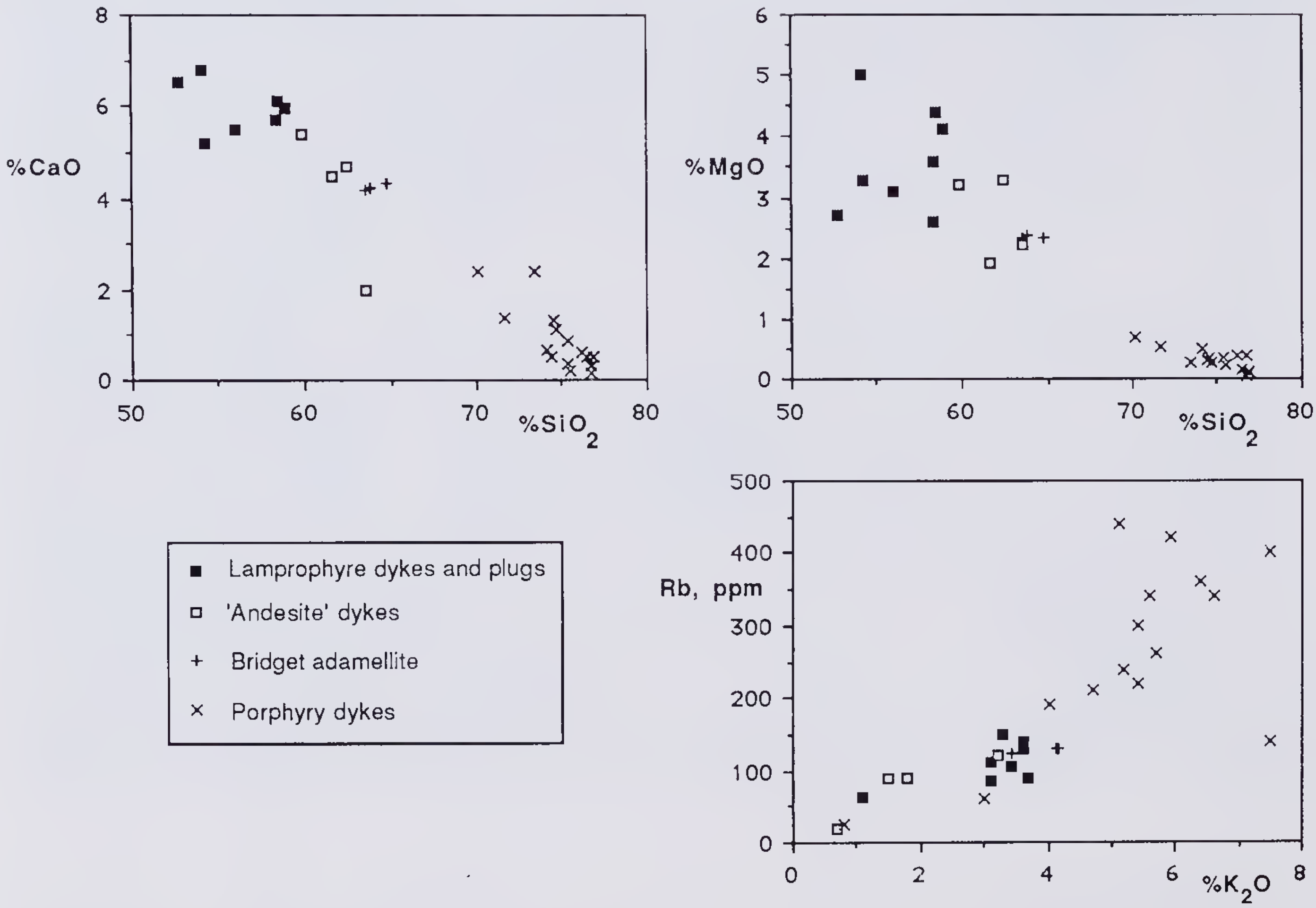

Figure 4 Variation diagrams illustrating coherent trends for geochemically homologous elements in the inferred Proterozoic lamprophyre-porphyry minor intrusive suite of the eastern Pilbara. Data from Table 1, Lewis & Davy (1981) and Barley (1980 unpubl; details available on request). Lamprophyre dykes and plugs are from near Bamboo Creek and the Bridget Adamellite, 'andesite dykes' are hornblende-plagioclase porphyry dykes from the Mt Edgar Batholith, and porphyries are silicic porphyries from the Mt Edgar Batholith.

Limited available data, illustrated in Figure 4, suggest that the spessaritites, hornblende-plagioclase porphyries from the Mt Edgar Batholith ('andesite dykes' of Lewis & Davy 1981) and the Bridget Adamellite form a fairly coherent geochemical suite. Note, however, that whilst the hornblende-plagioclase porphyries overlap the granitoids in composition, the spessartites are more basic than any of the known plutonic rocks. Silicic porphyries from the Mt Edgar Batholith are also plotted on Figure 4. Some of these are spatially related to lamprophyre and quartz monzonite intrusions, plot on extensions of the lamprophyre-quartz monzonite trend, and may also be genetically related.

Williams (1987, in press) records plugs of "microcline-biotite trachyte or lamprophyre" from the vicinity of Balfour Downs (Fig. 1), thus extending the belt of presumed Proterozoic lamprophyric magmatism in the eastern Pilbara to at least 250 km. These rocks intrude the Fortescue and Hamersley Groups, and range in composition from trachyte, with phenocrysts of albite and microcline set in a fine-grained feldspathic groundmass (also coarser grained albite-microcline granite), to minette (calc-alkaline lamprophyre dominated by biotite-orthoclase), containing biotite phenocrysts in a variably altered feldspathic groundmass with small apatite and magnetite euhedra. The relationship between the minettes and the spessartites further north is as yet uncertain, although such rocks commonly coexist in regional dyke-swarms, where they may even be heteromorphic (Rock 1984, Rock *et al* 1986b).

Conclusions

The eastern Pilbara spessartites appear to represent mafic end-members of a previously unrecognized lamprophyre-porphyry-minor intrusive suite, typical of examples accompanying other calc-alkaline granitoids of many ages on all six continents (Rock 1984, 1987). Unfortunately, detailed data as yet are few, and some of the available trace element analyses are only semi-quantitative (Lewis & Davy 1981). Features which nevertheless ally these minor intrusions with better-substantiated lamprophyre-porphyry associations elsewhere include the following:

(a) the chemical gradation in Figure 4 (*cf* Barnes *et al* 1986, Rock *et al* 1986b);

(b) the occurrence of lamprophyres as plugs satellite to granitoids, notably plugs adjacent to the Bridget Adamellite and similar granitoids near Bamboo Creek (*cf* Rock *et al* 1986a,b);

(c) the occurrence of plutonic chemical equivalents to the intermediate and felsic but not to the lamprophyric dykes (*cf* Rock *et al* 1988a).

More detailed work is therefore in progress on this minor intrusive suite, to determine the full range of lamprophyres and associated granitoids, their petrogenesis, and their tectonic significance.

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